Preparing MetOp for Work

Launch, Early Operations and Commissioning

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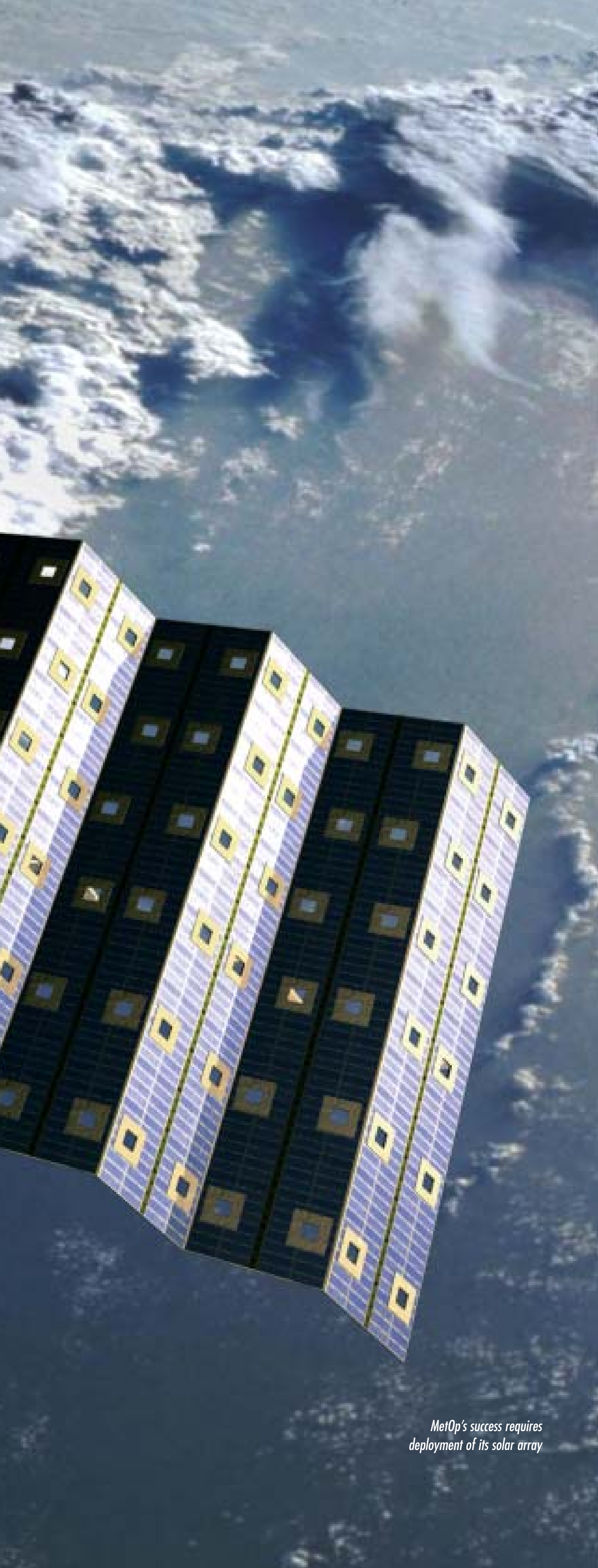
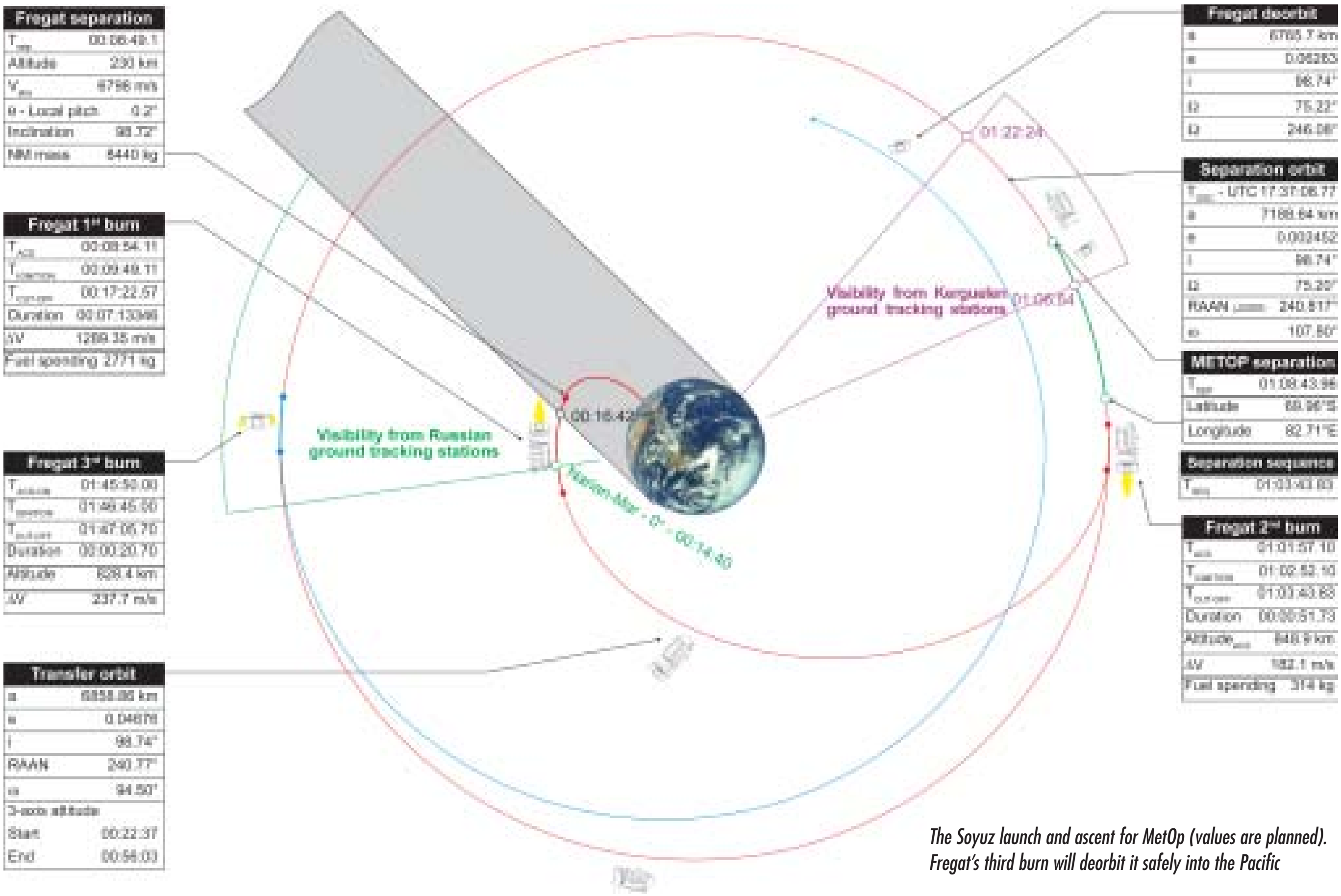


MetOp's success requires deployment of its solar array

The launch of MetOp will signal the beginning of a hectic schedule for the operations team at ESOC. It is their job to activate and test the satellite's most critical functions before handing it over to Eumetsat team for commissioning. All satellites have to be shepherded carefully through this process but MetOp's commissioning in orbit is particularly complex because of its solar array deployment and numerous instruments.

Introduction

The goal of the Launch & Early Orbit Phase (LEOP) is for ground controllers to convert MetOp from its near-inert launch condition into an autonomous satellite. The critical event is successful deployment of the solar array, as MetOp's batteries alone can provide enough power only for three orbits. After the 3-day LEOP, the lengthy Satellite In-Orbit Verification (SIOV) begins, systematically switching on and checking all of MetOp's systems and instruments; this will take about 3 months. Finally, in 2007, MetOp's services can be progressively brought online for users.



The Soyuz launch and ascent for MetOp (values are planned). Fregat's third burn will deorbit it safely into the Pacific

Launch & Early Orbit Phase

From launch campaign to LEOP

MetOp's Launch & Early Orbit Phase is handled by ESA's European Space Operations Centre (ESOC) in Darmstadt (D) under contract to Eumetsat. Responsibility for the satellite resides with prime contractor EADS-Astrium before launch and then shifts to ESOC's flight operations team just before lift-off after MetOp's hardware and software are switched into the launch configuration. Before lift-off, ESOC has access for a final check of the telemetry and telecommand interfaces, and of MetOp's onboard software to verify the programming of the attitude and orbit control system (AOCS) and the telemetry recording setup for when ground stations are out of sight. MetOp will be launched with its batteries fully charged, with the central flight software waiting for separation to trigger the automatic sequence for deploying the solar array. Deployment is programmed in for a set time (1 hour 52 minutes) after launch, allowing for visibility from the network of LEOP ground stations.

Launch and ascent

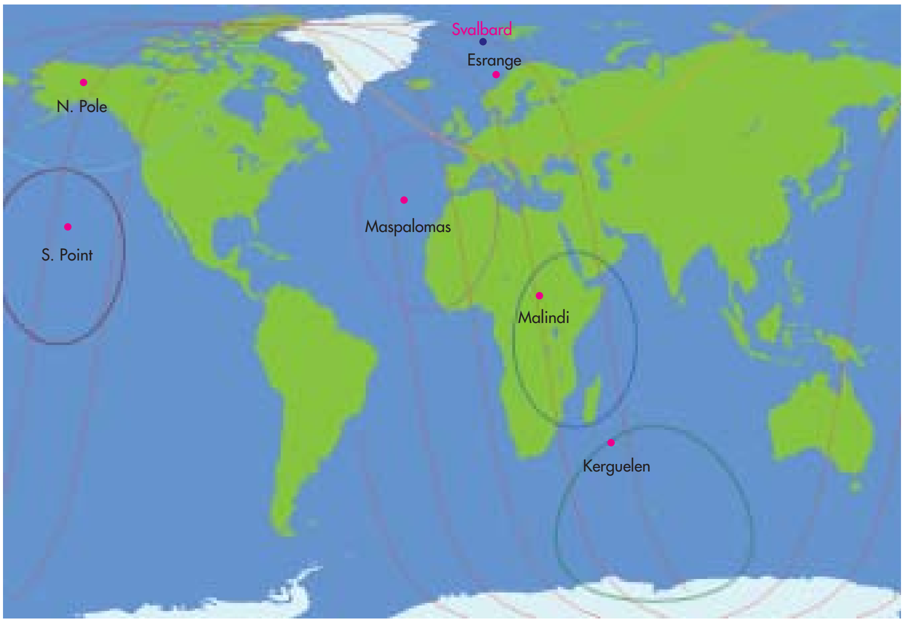
The time between lift-off and satellite separation is 68 min 59 sec, within range of the Kerguelen station. For MetOp, Fregat's first burn will be the last event that can be monitored by the Russian ground stations, before a long autonomous coast without coverage. Several measures will therefore be taken to increase the chances of seeing the Fregat/MetOp composite in the event of faulty injection or separation, maximising the odds of recovering the satellite. A wide-beam antenna has been added to the standard LEOP station at Kerguelen in order to monitor MetOp's separation. The Svalbard Control & Data Acquisition (CDA) station used by Eumetsat for routine operations and ESA's Kiruna station will also monitor part of the coast to confirm a normal ascent. The US NORAD military system will track the Fregat/MetOp ascent and provide independent orbital information.

LEOP infrastructure and organisation

LEOP involves a distributed network of ESOC personnel, a Eumetsat representative and an ESTEC/Astrium Project Support Team. The core LEOP mission control capabilities are built around the SCOS 2000 software kernel, using a Mission Reference Data Base from Astrium. Procedures for handling normal and recovery situations were developed by ESOC and proved during the satellite system validation tests or using the MetOp simulator. The flight dynamics team is responsible for

LEOP Ground Stations

Station	*Location*	*Latitude/Longitude*
Malindi	Kenya	2.99°S/40.19°E
Esrange	Kiruna	67.9°N/21.1°E
N. Pole	Alaska	64.8°N/147.5°W
S. Point	Hawaii	19.0°N/155.6°W
Kerguelen	Kerguelen	49.35°S/70.25°E
Maspalomas	Spain	27.76°N/15.63°W



MetOp visibility from the LEOP ground stations

updating MetOp's AOCS parameters during LEOP, planning and carrying out orbital manoeuvres, and routine activities such as orbit prediction.

MetOp control is performed via a network of S-band ground stations around the world. The stations are optimised to cover the solar array deployment, to monitor AOCS operation and payload deployments, and more generally to provide coverage during particularly critical activities in case of problems.

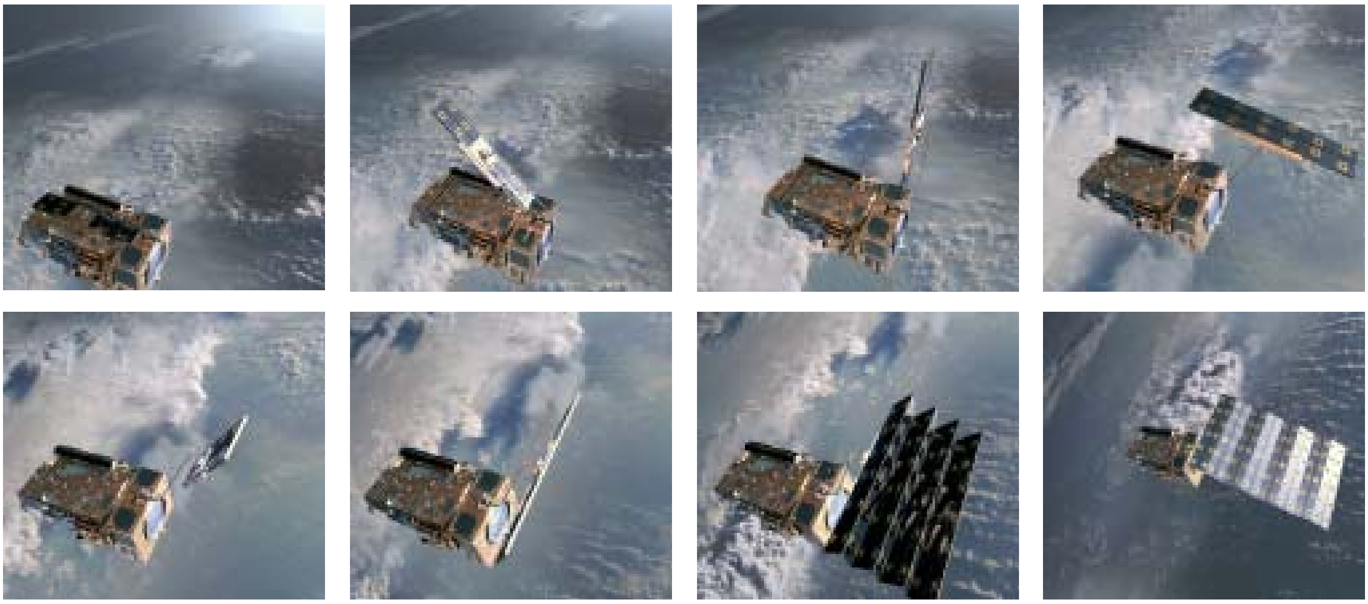
The mission control and support teams are trained to interact and optimise their responses to identify anomalies, and to formulate and agree upon recoveries quickly. They can quickly identify appropriate procedures during normal operations or well-identified failures, create new procedures to cope with unexpected anomalies, and safely command MetOp under pressure. LEOP simulations before launch are invaluable in preparing for flawless satellite operations during LEOP.

LEOP milestones

The main objective of LEOP is to put MetOp into an operational and autonomous condition. This requires the following sequence of events:

Main LEOP Activities	*Mission Elapsed Time*	*Ground Station Coverage*
From Launch to Operational Mode		
Lift-off	0:00:00	–
Separation	1:08:59	Kerguelen
SA thermal knives activation	1:09:11	Kerguelen
SA primary deployment driving (root hinge)	1:25:39	Malindi
SA primary deployment driving (mid and top hinge)		Out of coverage: telemetry recording and dump
SA secondary deployment driving	1:43:01	Esrange
Rate Reduction Mode	1:51:11	Esrange
MEGS unlocking/SFM enabling	**1:52:20**	**Esrange**
Fail-safe point → Solar Array deployed		
Coarse Acquisition Mode	1:52:20	Esrange
Reaction wheels unblocking	1:52:29	Esrange
End of automatic sequence	1:52:29	Esrange
Transition to FAM1	1:56:00	Alaska
MEGS rotation start	2:13:03	Alaska
Transition to FAM2	2:28:06	Out of coverage: telemetry recording and dump
Enabling of onboard surveillances for autonomous failure detection, isolation and recovery	2:49:47→6:56:19	Kerguelen, Malindi, Esrange, Alaska, Hawaii, Maspalomas
Flight Dynamics presents MetOp orbit information	8:00:00	
Command transition to OPM/GEO and verify convergence	10:23:28→14:58:50	Alaska
Payload Module initialisation & antenna deployment		
PMC, TCU, PCU, PDU initialisation	14:58:50→17:05:59	Hawaii, Alaska, Esrange
Verify PLM thermal stabilisation	20:25:50	Esrange
ASCAT RF antenna deployment	25:25:09→25:33:09	Esrange
ASCAT RA antenna deployment	27:08:09→27:22:09	Esrange, Alaska
GRAS (GAVA and CRA) and LRPT antennas deployments	28:39:09→29:03:39	Maspalomas, Esrange, Alaska
RTU initialisation	33:58:34	Alaska
Manoeuvres & handover to Eumetsat		
In-plane or/and out-of-plane manoeuvres, depending on Fregat/MetOp separation performance	47:33:44→ ?	All LEOP network
Eumetsat commandability checks	66:04:57	All LEOP network, plus Eumetsat CDA station
Latest handover to Eumetsat for SIOV	16:28:51	Esrange/CDA

LEOP chronology and coverage. CDA: Control & Data Acquisition. CRA: Combined Receive Antenna. FAM: Fine Acquisition Mode. GAVA: GRAS Anti-Velocity Antenna. GEO: Geocentric Pointing. MEGS: Mecanisme d'Entrainement du Generateur Solaire. OPM: Operational Mode. PCU: Power Conversion Unit. PDU: Power Distribution Unit. PLM: Payload Module. PMC: Payload Module Computer. RA: Right Aft. RF: Right Forward. RTU: remote terminal unit. SA: solar array. SFM: safemode. SIOV: satellite in-orbit verification. TCU: Thermal Control Unit. Payload acronyms are explained in the companion article 'The MetOp Satellite'



The deployment sequence of MetOp's solar array

– the automatic deployment of the solar array involves the primary deployment of the root, mid and top hinges, and the secondary deployment that extends and tensions the solar panels. This complex sequence of cutting Kevlar cables by thermal knives and activating motorised hinges will be triggered by the satellite separation. This step is particularly important because MetOp relies on its internal batteries until the solar array is able to provide power; the satellite can survive for only three orbits on batteries.
– achieving the correct orientation using thrusters and its fine-tuning to the operational mode via reaction wheels and magnetotorquers.
– the deployments of the antennas for ASCAT, GRAS and LRPT (Low-Resolution Picture Transmission). Some could interfere with thruster firings in the event of an emergency situation, so they have to be completed as quickly as possible.
– orbit adjustment to account for possible separation errors.

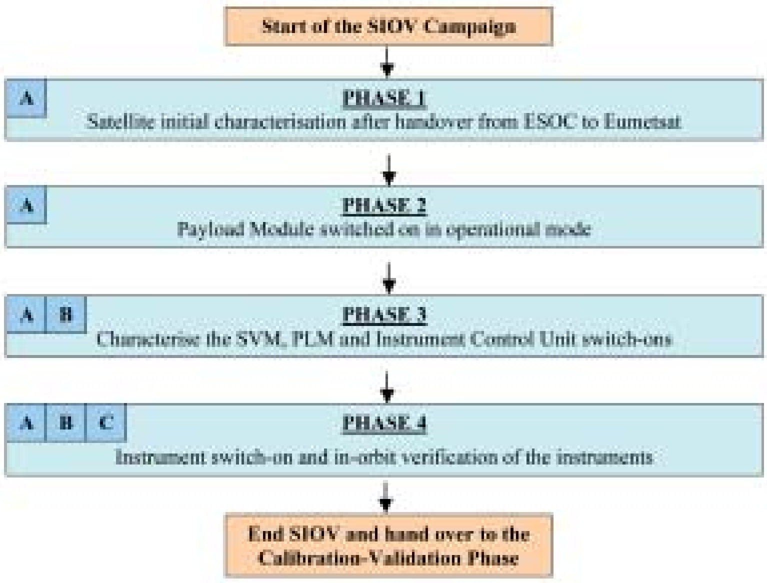
Three days are allocated for the overall LEOP, with a fourth kept in reserve.

Handing Over MetOp to Eumetsat

For MetOp's handover from ESOC to Eumetsat, the Service Module will be fully operational. Some of the instruments will be switched on, with the computer, remote terminal units, thermal control and power systems on. Eumetsat will test several functions before taking full mission control, including:

– acquisition and decoding of mission data from ESOC in order to ensure continuity and consistency of commands.
– telemetry, telecommand and ranging by the Eumetsat station in Svalbard.
– acquisition and processing of MetOp house- keeping telemetry.
– commanding the satellite.

After checking these vital functions in less than a day, the formal start of Satellite In-Orbit Verification (SIOV) will be declared 4 days after launch.



The main phases of SIOV activities. A: analysis of housekeeping telemetry. B: analysis of science data format. C: analysis of science data content. PLM: Payload Module. SVM: Service Module.

ESOC will remain on hot standby for 2 weeks in case of emergencies severe enough to threaten the mission. If that happens, the Payload Module will be switched off and ESOC will begin the recovery process.

Satellite In-Orbit Verification

SIOV will systematically switch on all of MetOp's functions and verify the performances of the Service Module, Payload Module and instruments. This is a complex phase that involves all the actors in MetOp and the Eumetsat Polar System; it demands strict planning and uses specialised tools for mission analysis and performance verification. The Svalbard CDA station will provide contact with MetOp for at least 10 minutes every orbit. For the instruments, the length of the in-orbit validation varies, ranging from 3 weeks for MHS to 3 months for IASI, which requires long decontamination before it can be operated.

SIOV objectives

The first objective is to verify that the satellite and its instruments are operable, by commanding them and observing the telemetry.

The second objective is to verify that the scientific data can be provided according to specifications via the onboard recorder and the X-band dump, and in real-time using the High/Low-Resolution Picture Transmission (HRPT/LRPT) regional broadcast system.

The third objective is to verify that the instruments are performing as expected by checking that their engineering data match those from the ground tests. The range of SIOV tools to do this was either specially developed or adapted from ground equipment.

The SIOV timeline

Design and operational constraints of the satellite and ground segment had to be respected in elaborating the SIOV timeline. These activities normally follow three main steps: initial characterisation after handover from ESOC to Eumetsat based on housekeeping telemetry received in S-band; switching the Payload Module into its operational mode, allowing the first tests of science data continuity and format; detailed verification of the in-orbit performance of the instruments using the SIOV ground tools.

The SIOV organisation

In line with the respective responsibilities for developing the satellite, the definition and coordination of the SIOV is delegated by Eumetsat to the joint Single Space Segment Team. The planning and implementation of this complex task involves the various partner space agencies (Eumetsat, CNES, NOAA and ESA) and companies (EADS-Astrium France, EADS-Astrium Germany and Galileo Avionica). Spread over a number of sites, it requires very strict organisation of team functions and tasks, from management to execution levels. Decisions involving satellite commanding are by nature critical and must be based on careful data analysis and rigorous procedures, for example through Anomaly Review Boards. To support SIOV, a complex data and information delivery system was set up to ensure timely access to data for the various participants. The SIOV uses specialist engineers to monitor 'their' subsystems or instruments at Eumetsat, and performance-verification teams operating remotely for specific data analysis. The SIOV will be reviewed on a daily basis to accommodate problems and recoveries that affect the overall schedule.

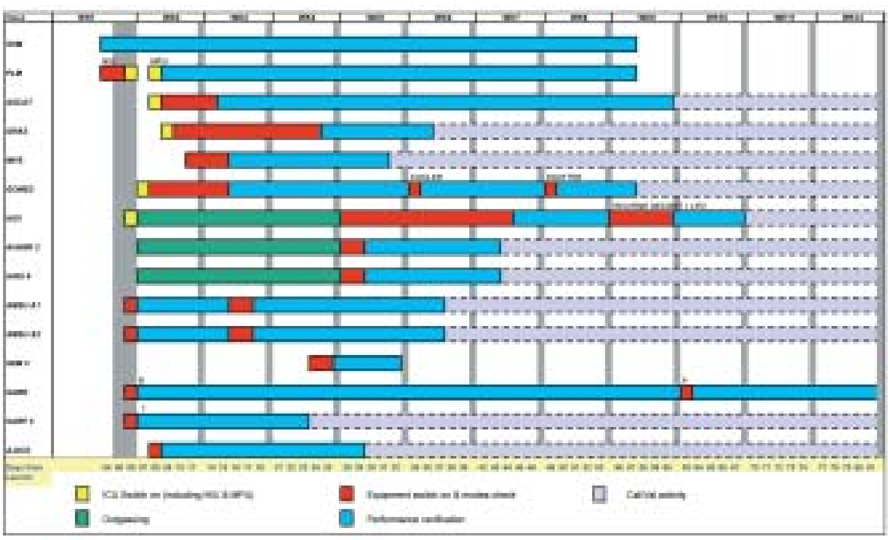
The outcome will be documented through a data package presented to Eumetsat at the SIOV system review. Lessons-learnt for the MetOp-B and MetOp-C SIOVs will be identified.

EPS Verification and Validation Phase

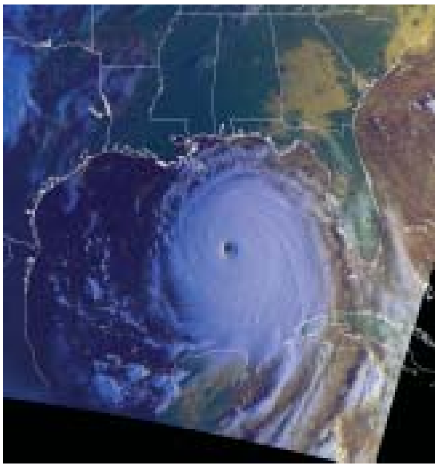
Once the MetOp satellite has been verified in orbit, the Verification and Validation of the full Eumetsat Polar System (EPS), and in particular of its services to the users and its meteorological products, can formally begin. Considering that the SIOV durations vary with each instrument, a progressive release of 'instrument chains' from SIOV into system validation is planned.

The activities at system level during this period can be grouped into two main areas:

- verification and validation of the main EPS ground system functions, data flows, links and services to the users.
- calibration and validation activities for the centrally generated EPS products.



Chronology of SIOV activities



Once commissioned, MetOp will be able to return valuable images such as this: Hurricane Katrina captured by the AVHRR instrument of NOAA-15 on 28 August 2005 (NOAA)

EPS system and services verification and validation

These activities start progressively, often in the background of SIOV operations. They are formally completed only once the corresponding satellite functions are formally verified, at the end of the SIOV phase. They include:

– precise characterisation of the space-to-ground links (S-band, X-band, HRPT, LRPT). This begins as soon as the transponders are switched on.
– HRPT/LRPT local broadcast service verification, starting after the HRPT/LRPT switch-on 5 days after launch, with a verified service available after about a week. This work is completely combined with the SIOV work, for efficiency.
– verification of the Level-0 (raw) data archive & retrieval service. This started when the first instrument data were acquired, about a week after launch. A verified service limited to Level-0 will therefore be available to the SIOV partners (ESA, NOAA, CNES) within a few days. When early Level-1 (uncalibrated) meteorological products are generated, the service will be extended to these products.
– the EUMETCast near-realtime data and products dissemination service will be used to transfer Level-0 data to the partner organisations during SIOV. This begins when level-0 data are available (a week after launch) and will last for the SIOV duration. Then, EUMETCast will be ramped up towards its operational configuration, adding verified Level-1 products as they become available. At the end of commissioning, the full complement of products indicated below will be available on EUMETCast.
– the readiness of the Global Telecommunication System depends on the readiness of the encoding of the EPS products and on the availability of the early products themselves. It is planned to be completed at the latest by the end of commissioning.
– NOAA cross-support services are part of the Initial Joint Polar System between NOAA and Eumetsat and cover the provision of support to NOAA blind orbits and MetOp Level-0 data exchange. These services provided by EPS to the NOAA ground segment will not be exercised initially during the SIOV phase and will be progressively established during the commissioning phase.
– Search & Rescue, Data Collection System Level-0 and Space Environment Monitor Level-0 services will be verified as part of SIOV and become available accordingly.

All EPS services to the users will be operationally validated by the end of the system commissioning at the latest, with the exception of the Level-2 (calibrated) product dissemination service.

Products: calibration and validation

Before launch, all EPS processing functions for Level-1 products (corresponding to geo-located, calibrated instrument data) were brought up to their target commissioning baseline, which incorporates all critical changes, bug fixes and updates to the product formats resulting from testing. This configured baseline is reflected in the product format information available on *www.eumetsat.int* and will be used for the initial processing of the data.

Thanks to the common instrument suite between MetOp and the NOAA-18 satellite launched in 2005, extensive testing could be performed using real NOAA data dumped to the Eumetsat CDA station in Svalbard or transferred by NOAA via the high-rate transatlantic link. These data were regularly processed in near-realtime within the EPS ground segment. This covered Level-1 products from the AVHRR, MHS, AMSU and HIRS instruments. All other Level-1 products from the IASI, GOME, ASCAT and GRAS instruments were tested before launch using real Metop data, synthetic data or modified data from satellites.

For each instrument chain, the logical sequence is:

– after the verification of an instrument and its release from SIOV, the correct geo-location and radiometry of the Level-1 products are verified using the tools at Eumetsat and partner-organisation premises. Then, the products are disseminated as preliminary validation products via EUMETCast.
– these Level-1 products are then validated over several weeks to several months. During this, the processing parameters are optimised. A Validation Report is produced at the end of the commissioning phase.
– validation of the Level-2 products can start only once the corresponding Level-1 products have been validated. This will begin some 6 months after launch for IASI and ATOVS. Early products will be released once verified. Specific sounding campaigns are planned.

The Organisational Challenge

The challenge of the MetOp LEOP and commissioning lies in the very complex cooperative and/or contractual arrangements of the numerous actors across Europe and the US. Managing LEOP and SIOV requires very clear coordination to keep a large number of distributed activities focused on the objectives over a long time.